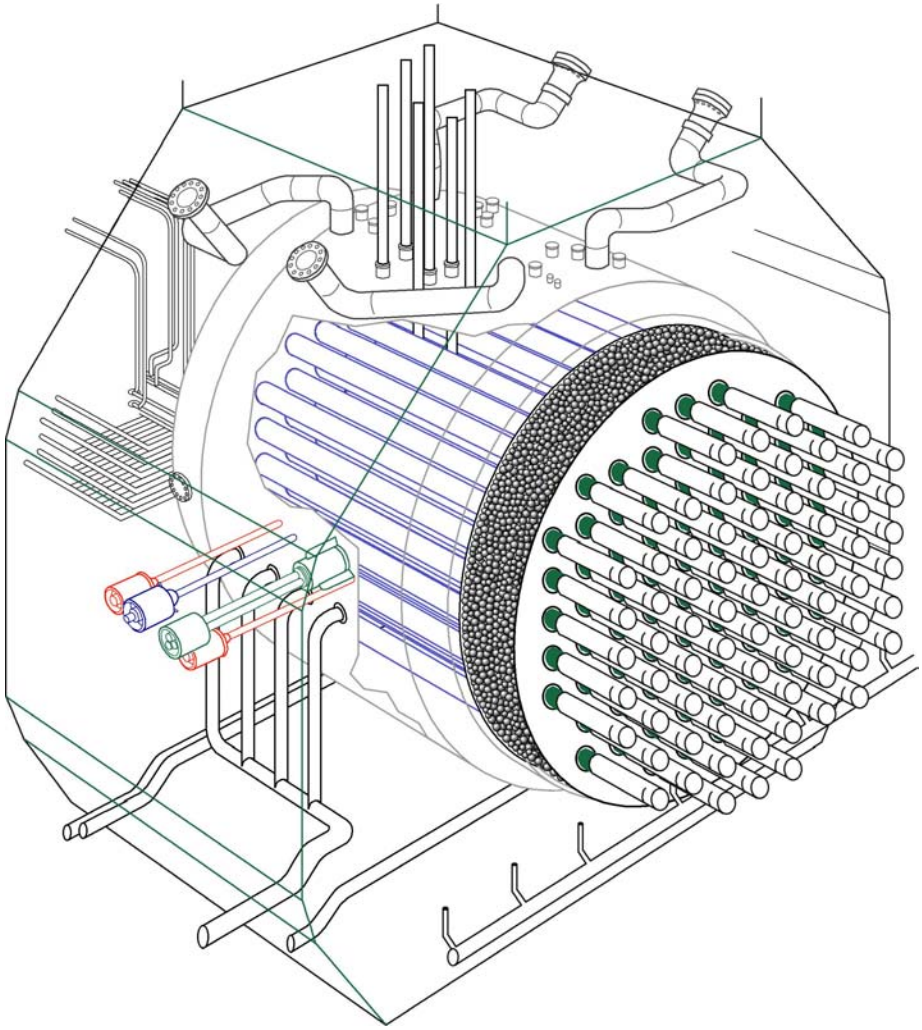
CANDU Fundamentals



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1 Objectives

1.1 Course Overview

CANDU Fundamentals is designed as an introductory course in the operation of a CANDU reactor. Starting with the basics of atomic theory the course explains the construction of the reactor, its major systems and enough reactor physics so that the participant will understand the control and operating practices in a CANDU plant. Emphasis is placed on nuclear safety and the systems that minimize the risk from fission products in the reactor core.

1.2 Atomic Structure

- Name the fundamental atomic particles.
- State the mass and electric charge if the fundamental particles.
- Describe an atom as pictured by the Bohr model.
- Recognize, interpret, and use the ${}^{A}_{Z}X$ notation for atoms (nuclides).
- Describe what the term isotope means.
- Recognize and use the names of the hydrogen isotopes.

1.3 Radioactivity – Spontaneous Nuclear Processes

- Write a typical equation for the production of each type of radiation: α, β, and γ.
- List the properties of each type of radiation: α, β, and γ.
- Discuss how each type of radiation interacts with matterα, β, and γ.
- State how to shield against alphas and betas.
- State how to shield against γ rays and calculate γ ray shielding in terms of ½-value layers.

1.4 Nuclear Stability and Instability

- Discuss the stability of nuclides in terms of neutron proton ratios and forces in the nucleus.
- From a plot of n against p, state the emission a given nuclide is likely to undergo.
- Given a chart or table of nuclides, list all members of the decay chain of a given radioactive nuclide.

1.5 Activity

- Define the common units of activity: Becquerel, Curie.
- Define the half-life and discuss activity in terms of half-lives.
- Solve simple activity and half-life calculations.

1.6 Neutrons and Neutron Interactions

- Write equations describing each of the following neutron interactions: transmutation, radiative capture, photoneutron reaction with deuterium.
- Describe elastic and inelastic scattering of neutrons.

1.7 Fission

- State where the energy released by fission comes from (mass to energy conversion).
- Write a typical fission reaction.
- State how much energy a fission releases.
- State how the major portion of the energy from fission is carried away.
- Define each of the following: thermal neutrons, fast neutrons, prompt neutrons, delayed neutrons.
- Describe what is meant by neutron cross-section and neutron flux.
- Explain a self-sustaining chain reaction.

1.8 Fuel, Moderator, and Reactor Arrangement

- Explain the purpose of a moderator.

- Sketch the basic arrangement of fuel and moderator in a CANDU reactor.

- Explain why the arrangement of fuel and moderator in a CANDU reactor is used.

- State the basic differences between fresh and equilibrium fuel.

- Compare the moderating properties of heavy water, light water, and graphite.

1.9 Nuclear Safety

- Describe the makeup of background radiation, and state how much nuclear stations contribute to it.

- State what is meant by Defence in Depth.

- Describe the five parts of the Defence in Depth model.

- List the five barriers that protect the public from fission products.

- Explain how the principle of Control, Cool and Contain guides reactor operation.

- Explain how the following concepts contribute to the reliability and/or availability of systems or equipment: redundancy, independence, diversity, periodic testing, fail-safe operation, operational surveillance, preventive maintenance, and predictive maintenance.

- State the purpose of the following documents: Safety Report, Station Operating Licence, Operating Policies and Principles (OP&Ps), Operating Procedures, and Certificates of Approval.

- State the possible consequences of an OP&P violation.

- Describe how the authorization of some positions supports nuclear safety.

1.10 Nuclear Power Reactors

- State the type of fuel, coolant and moderator used in a CANDU reactor.

- Give the advantages and disadvantages of a nuclear power plant compared to a fossil fuelled plant for each of the following: economics, energy production flexibility, environmental considerations.

1.11 CANDU Reactor Construction

- State the function of each of the following reactor components: pressure tube, calandria rupture disc, calandria tube, annulus gas, end fitting, feeder pipe, closure plug, fuelling machine, fuel latches, biological and thermal shield, end shield, shield plug, shield tank, reactor vault.

- Given a diagram of a fuel channel or an end fitting in a reactor face, label the following components: end fitting, channel closure plug, feeder coupling, annulus bellows, journal bearings, fuel bundle, pressure tube, calandria tube, calandria-side tube sheet, liner tube, shield plug, end shield, fuelling machine-side tube sheet.

- State the purposes of the annulus gas system.

- Describe three advantages of the CANDU pressure tube design compared to a pressure vessel design.

1.12 Moderator and Moderator System

- Define the term isotopic and state the importance of maintaining the isotopic as high as possible.

- State the purpose of a D_2O upgrader.

- State the three main radioactive isotopes produced in the moderator.

- Describe the radiation hazard associated with each isotope.

- State the two major reasons why the rate of tritium production in the moderator is greater than in the heat transport coolant.

- State two purposes of the moderator circulation system.

- State the three main moderator heat sources.

- State why a backup cooling arrangement is needed.

- Given a diagram of a moderator, circulating system label the following major system components: pumps, heat exchangers, moderator temperature control valves.

- Describe how moderator temperature is controlled.

1.13 Moderator Cover Gas System & Moderator Auxiliary Systems

- Given a diagram of the main moderator system, show where the purification system is connected.

- State the three major functions of a moderator cover gas system.

- State two additional functions for the moderator cover gas system for a reactor with a dump tank.

- Given a diagram of a moderator cover gas system label the following: compressors (two functions), recombination unit, heat exchanger, recombination unit inlet heater, flame arrestors.

- State the function of each of the following components of the moderator cover gas system: compressors (two functions), recombination unit, heat exchanger, recombination unit inlet heater, flame arrestors.

- State the role of gas chromatography in the cover gas system.

- State why the following gases are sometimes added to the cover gas system: oxygen, helium.

- State the function of each of the following moderator auxiliary systems: purification system (two functions), liquid poison addition system, D_2O collection system, auxiliary cooling.

- State the importance of maintaining the chemical purity of the moderator D_2O as high as possible.

- Given a diagram of the moderator purification system, label the following major system components and state their function: ion exchange columns (IX columns), filters, strainers, purification coolers.

- Name the two neutron absorbing poisons added to moderator D_2O.

- List four points from which moderator D_2O is routinely collected.

1.14 Heat Transport System

- State the two purposes of the heat transport coolant.

- Discuss the nuclear and conventional hazards that may be present around heat transport system equipment in the plant.

- Given a diagram of a typical heat transport system (HTS), label the major components: HTS Circulation pumps, fuel channel, reactor inlet header, reactor outlet header, feeders (feeder pipes), boilers/steam generators.

- Explain why bi-directional flow is used in HTS operation.

- State why HTS pumps are placed after the boilers in the main HTS circulating system.

- State the purpose of the shutdown cooling system.

- Explain the importance of circulation by natural convection to HTS operation.

1.15 Heat Transport Auxiliary Systems

- State the two major purposes of the heat transport pressure and inventory control system.

- Given a diagram of a pressure and inventory control system, label the diagram showing the following components: pressurizer, pressurizer steam bleed valves, pressurizer heaters, feed valves, bleed valves, feed pumps (pressurizing pumps), bleed condenser, bleed cooler, D_2O storage tank.

- State the function of each of the following components: pressurizer, pressurizer steam bleed valves, pressurizer heaters, feed valves, bleed valves, feed pumps (pressurizing pumps), bleed condenser, bleed cooler, D_2O storage tank.

- State the function of each of the following HTS auxiliary systems: Pressure relief system, Purification system, HTS D_2O

collection system, HTS D_2O recovery system, Fuelling machine D_2O supply.

- State the importance of chemical control in the HTS.
- State the function and basic principle of operation of the HTS pump gland and gland seal supply system.
- State why HTS D_2O is not added to moderator and why moderator D_2O is not added to HTS D_2O.
- State two reasons why there is more leakage from the heat transport system than from the moderator system.
- List four typical heat transport system leakage collection points.

1.16 Reactor Fuel

- Define the term failed (defective) fuel.
- State how normal CANLUB fuel is used and why it has this name.
- Given a diagram of a fuel bundle, label the following components: fuel element, fuel sheath, fuel pellet, end plate, bearing pad.
- State seven characteristics (two nuclear and five non-nuclear) that the fissile fuel material should have.
- State four characteristics (one nuclear and three non-nuclear) that the fuel sheathing material should have.
- Give three ways the CANLUB graphite layer helps prevent fuel defects.
- Explain six precautions taken in the handling of fresh fuel.
- Explain three precautions required when handling spent fuel.
- Describe the general process followed during refuelling of a channel.
- State three in-plant operational consequences of leaving failed fuel in the reactor.

- State and explain two uses of depleted fuel and give the U-235 concentrations for normal and depleted fuel.

1.17 Neutron life cycle

- Sketch the life cycle of a neutron including all possible fates of the neutron.

- Discuss why reactors use reflectors.

1.18 Criticality and Neutron Multiplication

- Define the neutron multiplication constant (k).

- Define reactivity (Δk) and state its common units.

- Discuss what is meant by sub-critical, critical, and super-critical in terms of the values of k and Δk and state whether power is increasing, decreasing, or remaining constant.

- State and explain how the reactor can be critical at any power level.

- Given a method of criticality control, discuss how it affects the neutron cycle.

1.19 Changes In Reactor Power With Time

- Define Reactor Period.

- Explain why and how delayed neutrons affect changes in reactor power.

- Explain why power does not drop to zero in a sub-critical core.

1.20 Xenon: A Fission Product Poison

- Explain why xenon is the most important fission product poison.

- Explain how xenon is produced in, and how it is removed from the reactor.

- Sketch xenon concentration as a function of time for a shutdown or trip from full power.

- Discuss the phrase xenon poison out.

1.21 Reactivity Effects of Temperature Changes

- Define the following terms: temperature coefficient of reactivity, void reactivity, power coefficient

- Explain why and how reactivity changes when the temperature of the fuel changes.

- Explain why a negative temperature coefficient is desirable.

1.22 Neutron Flux Control

- Explain why a flat flux distribution is desirable.

- Explain how each of the methods used in CANDU reactors flattens the flux.

- Explain what flux oscillations are and how liquid control zones are used to prevent them.

1.23 Reactivity Mechanisms

- State how core reactivity (long term) is normally maintained.

- State the two general functions of reactivity mechanisms.

- For each of the following reactivity mechanisms, state whether it is used for reactor power regulation or protection: liquid zone control, absorber rods, adjuster rods, shutoff rods, liquid poison addition, liquid poison injection, moderator level, moderator dump.

- Describe the principle of operation of each of the three types of protective shutdown systems found in CANDU reactors.

- Describe how the two-out-of-three trip logic triggers an emergency shutdown system.

- State three advantages of using two-out-of-three trip logic.

- Define the term fail-safe.

- Describe how fail-safe design contributes to the reliability of a safety shutdown system.

1.24 Emergency Coolant Injection & Containment

- Name the four special safety systems designed to protect the public from radiation.

- Explain the purpose of the containment system.
- Explain the purpose of the emergency coolant injection system.
- Given a diagram of the emergency coolant injection system: high pressure water supply, isolation (or injection) valves, recovery sump, recovery pumps, recovery heat exchangers, low pressure water.
- Explain the purpose of each of the following components in an ECI system: high pressure water supply, isolation (or injection) valves, recovery sump, recovery pumps, recovery heat exchangers, low pressure water
- Describe the basic operation of the emergency coolant injection system in response to a loss of coolant accident (LOCA).
- Describe two types of containment systems used for CANDU reactors.
- Given a diagram of a negative pressure containment system, label the following components: the dousing tank, pressure relief valves, a vacuum duct, the pressure relief duct, the containment structure, and the vacuum building.
- Given a diagram of a pressure suppression containment system, label the following components: the dousing tank, a dousing valve, the containment structure.

1.25 Conventional Side

- State the two major functions of the steam and feedwater cycle.
- Describe the condition of the steam (moisture, temperature, pressure) at each of the following locations in the steam path: outlet of high-pressure turbine, outlet of moisture separator, outlet of reheater, and outlet of low-pressure turbine.
- State the function of the turbine-generator set.
- Describe the need for both high and low pressure turbines.
- Explain the advantage of having a vacuum in the condenser during operation.

- Given a diagram, label the following components, show the main steam and water connection between them, and indicate the direction of flow: boiler (steam generator), safety valve, atmospheric steam discharge valve (ASDV), emergency stop valve, governor valve, HP turbine, moisture separator, reheater, LP turbine, condenser, condensate extraction pump, feedheaters, deaerator, and boiler feed pump.

- State the purpose of each of the following components of the steam and feedwater cycle: boiler (steam generator), safety valve, atmospheric steam discharge valve (ASDV), emergency stop valve, governor valve, HP turbine, moisture separator, reheater, LP turbine, condenser, condensate extraction pump, feedheaters, deaerator, and boiler feed pump.

- Explain how an alternative heat sink is provided if the turbine is unavailable for operation.

- Describe the process for preparation of the condensate before it is returned to the boiler.

- Describe the turbine generator lubricating system.

- State the purpose of the turning gear.

- State the reasons and methods for maintaining good chemistry in the steam and feedwater.

1.26 Other Major Systems

- Describe how an AC generator produces electrical energy.

- Explain how heat is generated in and removed from a large AC generator.

- Describe the major hazards associated with the boiler, turbine, generator, steam and feedwater system.

- State the purpose of each of the following: main output transformer, switchyard, unit service transformer, and system service transformer.

- Name the four classes of power used in a CANDU station, and explain the purpose of these classifications.

- Name the power source which supplies power when one or both Class IV power sources fail.

- State the function of the Emergency Power Supply (EPS).

- Given a diagram, label the following light water systems: water treatment, condenser cooling water, common service water, unit low pressure service water, unit high pressure recirculating service water, and closed loop demineralized service water system.

- State the purpose of each of the following light water systems: water treatment, condenser cooling water, common service water, unit low pressure service water, unit high pressure recirculating service water, and closed loop demineralized service water system.

- State the purpose of the Emergency Water System (EWS).

- State the purposes of three separate air systems in a nuclear generating plant.

- State how equipment is identified in the station and on flowsheets.

- Describe how piping systems are coded and why.

- Briefly, describe major features of waste management for liquid and solid waste.

- Describe how D_2O is managed in a CANDU station to minimize losses.

- Describe the purpose and process of the tritium removal facility.